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The Repair of Foundry Defects in Steel Castings Using Welding Technology

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Abstract

Use of welding technology for the repair of steel castings is particularly common in two areas. These include weld surfacing of protrusions that remained incomplete after casting, or filling the surface defects (cavities). These defects are more common for steel casting than for graphite cast iron, due to the lower fluidity of steel. This article describes a suitable technological process of repairing the defects on the casting using the welding technology. A specimen produced for this purpose was prepared by carving a groove into a cast steel plate 20 GL, which was then filled with a weld metal using MAG (135) technology. The following evaluation of the basic characteristics of the repaired site point to the suitability of the selected technological parameters of the repair procedure. Metallographic evaluation was carried out, further evaluation of mechanical properties by tensile test, bend test and Vickers hardness test. The proposed methodology for the evaluation repair of foundry defects in steel castings also meets the requirements for the approval of welding procedures in accordance with the relevant valid legislation.

Keywords: Steel Castings, Repair by Welding, Mechanical testing, Approval of Welding procedures

1. Introduction

The cast steel is commonly used for various armatures, pressure vessels and turbine components, steam pipe and water pipe castings, parts of forming machines, parts of rolling stock chassis, etc. In terms of chemical composition, cast steel in most cases is similar to low or medium carbon moulded steel and its weldability predominantly depends on the content of carbon. However, if the content of carbon and additive elements is higher, it is necessary to consider other factors affecting the weld-ability of the steel [1,2-4].

Low carbon cast steel (with the content of carbon up to 0. 2 %) is the easiest to weld by the large number of usable welding methods. The resulting hardness in HAZ (Heat-Affected Zone) of low carbon steel rarely achieves high values because of the critical cooling rate, which is not normally exceeded. If the deoxygenation of the molten metal is insufficient, such steel is prone to porosity. Therefore, the additive materials used to weld such steel should contain higher amounts of deoxygenation elements (Al, Mn, Si).

For medium carbon steel (0.2 to 0.5 %), preheating is not generally required up to the content of carbon of 0.3 %. If this limit is exceeded, it is necessary to apply preheating and use the low hydrogen electrodes to eliminate the problems with cracks occurrence [1,3,5].

High-carbon steel (0.5-1.0 % C) is difficult to weld because of the formation of cracks around the weld. Therefore, it is recommended to ensure the following conditions for a welding process: the protection of a low hydrogen content welding bath, a welding technique that minimizes bath mixing and the resulting increase in the weld metal hardness. It is also used heat treatment after welding consisting of annealing at least, or homogenisation annealing to reduce internal stresses [6-11]. Filler materials for the cast steel welding can be selected as for rolled steel products. The basic requirements for welding the carbon steel are the chemical composition and mechanical properties of the filler materials equivalent to the material being welded. Fig.1 shows the parts of wagon chassis made from steel 20GL.

Fig. 1. Parts of wagon chassis made of cast steel [11]

The defects on castings are possible to repair by welding under specific conditions. The product standards in some specific cases require using approved technology for the repairs of such defects occurred in the foundry process to fulfil quality requirements. Therefore, experimental procedures for determining the optimum repair technology that will meet the requirements for the approval process specified in the applicable technical standard are described in this article.

2. Experimental part

2.1. Basic material

Experimental samples were made from cast steel being used for the production of rolling stock chassis for the Russian market. The steel designation is 20 GL according to the GOST standards, which are equivalent to the Slovak standard STN 42 2712 and it is the low-alloy cast steel. The basic properties of such cast steel are listed in Table 1. The thickness of the test specimen was 25mm. Cast plates were delivered in a condition after normalization annealing. The temperature of the normalization annealing was 920 °C, the heating rate 180°C/hod., holding time 180min. The sample was cooled in air.

Table 1.
Chemical composition and mechanical properties of the 20GL steel cast in mass % (condition after normalization annealed)

Designation according to GOST 977-88	C	Si	Mn	P	Cu	Cr	Ni	S
20 GL	0,19	0,35	1,22	0,012	0,09	0,07	0,04	0,007
R_eH [MPa]	R_m [MPa]		A_5 [%]		KCV [J]/ T= -60°C			
340	520		19,8		23,3			

2.2. Technological parameters of MAG welding of experimental samples

The geometry of the welding joint edges and the method of weld beads position for repairing narrow defects (for example cracks etc.) are shown in Fig.2. Welding joints have been made in accordance with the welding parameters as listed in Table 2.

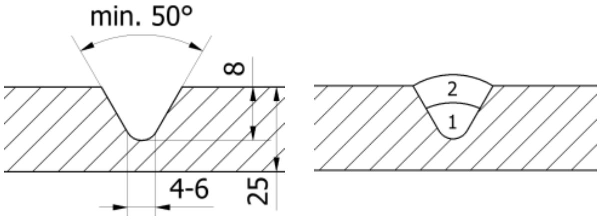

Fig. 2. Geometry of a welding joint and a method of weld beads position

Table 2.
Welding parameters during cast repair

Layer	Welding Current [A]	Welding voltage [V]	Welding speed [$mm.s^{-1}$]	Heat input [$kJ.mm^{-1}$]
1	250 - 260	23 - 25	0- 5	0. 92 – 1. 3
2	220 - 230	23 - 25	4 - 5	0. 92 – 1. 3

Note: DC welding current in the DC+ connection

As an filler material, GOLD G4Si1 (G 46 4 M4 Si1 according to standard EN ISO 14341-A, diameter Ø=1,2mm) has been used. For the used cast steel, preheating has only been designed under certain conditions for welding at the ambient temperature below 5°C, or if the resulting carbon equivalent exceeds the value of $C_E \geq 0.45$. The general principles designed by the producer and purchaser have been considered as well. Under these conditions, preheating at the temperature of 200 °C has been designed, wherein the interpass temperature in welding the cast steel was the same as the preheating temperature.

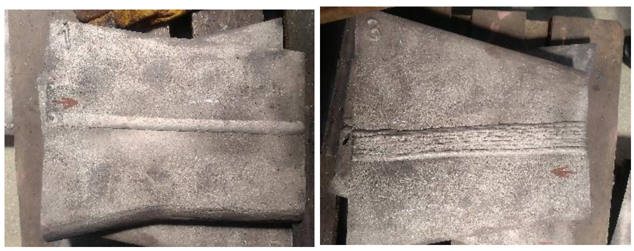

Fig. 3. Test sample with a weld deposit for repairing the crack and narrow defects (left) and for repairing flat defects (right)

The resulting application requirements for the 20 GL steel castings demanded heat treatment after welding, namely tempering at 560 °C (onset and rise to the temperature 180 min, duration 240 min) with furnace cooling down to 300 °C. These conditions were also set out in a test specimen. The experimental samples are shown in Fig. 3.

3. Testing of weld joints

The requirements for the quality of cast steel weld joints are defined in standard EN ISO 11970 - Specification and approval of welding procedures for production welding of steel castings. In compliance with this standard, the tests were required to perform as follows:

Non-destructive tests (NDT)

- visual testing (VT), EN ISO 17637 standard, defect classification: EN ISO 5817, quality level C,
- penetrant testing (PT), EN ISO 3425-1, EN 1371-1,2, EN ISO 23277, acceptability level 1,
- radiographic test (RT), EN ISO 17636-1, STN 42 1240, EN ISO 10675-1, acceptability level 2.

Destructive tests

Mechanical properties of test weld joints have been evaluated by means of the following tests:

- transverse tensile test, EN ISO 4136, EN ISO 6892-1,
- weld bending test, EN ISO 5173,
- impact testing, EN ISO 9016, EN ISO 148-1,
- hardness test, EN ISO 9015-1, EN ISO 6507-1.

4. Analysis of results

Any unacceptable defects have been detected in visual testing of a repair weld on the steel castings. Capillary testing has given the same results. Internal defects as pores (standard designation: 2011) have been identified on the records made in a radiographic test and their dimensions have always been within the required quality level (the largest dimension d $\leq$ 0.3.s, but max. 4 mm, where **d** is pore diameter and **s** is thickness of material).

The test bars for the tensile test were taken from the face of the weld to a depth of 8mm so that in this cross section the entire weld metal. After the bend test no cracks at the weld joint were observed (Fig. 4 on the left). The fracture area of the tensile test was observed outside the welding joint (Fig. 4 on the right).

Fig. 4. Test rods for weld bending test (left) and transverse tensile test (right)

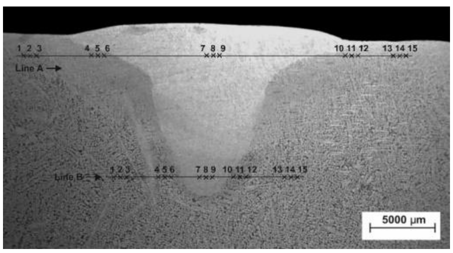

Fig. 5. The photo of the weld joint macrostructure with indicated lines and place of hardness measurement HV10

The stress strain diagram of the test rod is presented on Fig. 6 and Fig. 7 shows the hardness test curve HV10. The results of destructive tests done to determine mechanical properties of the weld on cast steel are shown in Table 3. The photo of the weld joint macrostructure is presented in Fig. 5. The photo of a butt weld macrostructure shows visible sporadic internal defects as pores (standard designation: 2011) whose dimensions do not exceed allowed values for the desired level of acceptability. In both cases, the welds were free of cracks and other unacceptable defects as stated in Table 1 of standard EN ISO 17639.

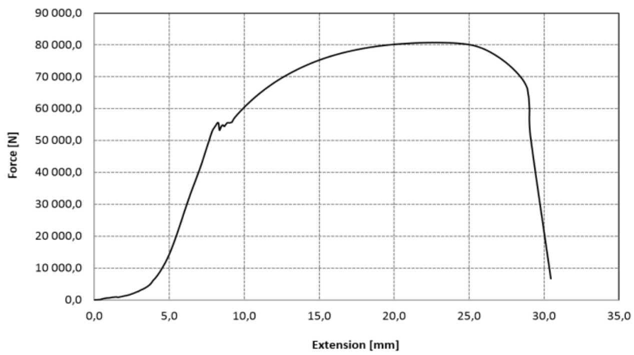

Fig. 6. Tensile Test Curve for 20GL steel cast after welding repairs

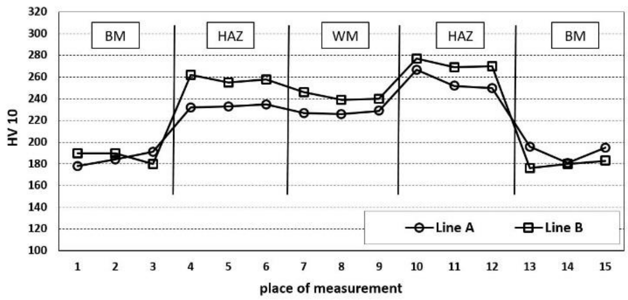

Fig. 7. Hardness HV10 of a weld joint
BM - base material, HAZ - heat affected zone, WM - weld metal

A microstructure test was also required to be done for the butt weld application on the cast steel. The purpose of such test was to evaluate the butt weld defects, the size of the material grains after welding and heat treatment. The photos of the butt weld single parts microstructure (Fig. 8, 9) do not show any unacceptable defects.

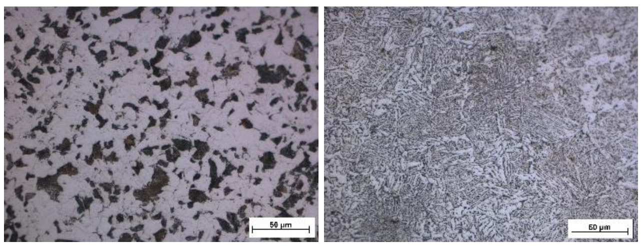

Fig. 8. The photo of the base material microstructure (left) and microstructure of HAZ (right)

Table 3.
Results of mechanical tests

Test methods	**Experimental sample /cross-section size**	**Measured values**	**Evaluation limits**
Transverse tensile test	A flat specimen for a tensile test / 8x20 mm	R_m = 526 to 540 MPa	min. R_m = 465.5 MPa [a)]
Bend tests	Side bend test specimen SBB / 10x25 mm	Without cracks and other defects	Without cracks and other defects larger than 3mm
Impact tests (at the temperature T= -60 °C)	Test specimen VWT / 10x7,5 mm [b)] Test specimen VHT / 10x7,5 mm [b)]	KCV = 58 to 141 J/cm^2 KCV = 59 to 69 J/cm^2	min. KCV = 16,7 J/cm^2 min. KCV = 16,7 J/cm^2
Hardness testing (HV10)	Used the same particle as for macrostructure evaluation	ZM: max. 196 HV [c)] TOO: max. 270 HV ZK: max. 246 HV	max. 380 HV

[a)] Strength must not be lower than the strength of the parent material by more than 5 %
[b)] Due to the weld size, the reduced particle thickness w=7. 5mm was applied
[c)] Hardness was measured in a line (R), one line in the root zone, one line in face of a weld (each metallurgical zone 3 indentations)

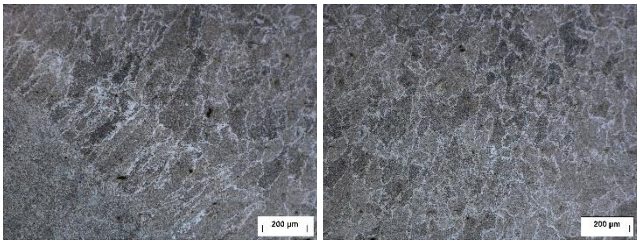

Fig. 9 The photo of the fusion line microstructure (left) and weld metal microstructure (right)

In addition to the technical standard applicable for macroscopic and microscopic analyses, *standard EN ISO 643 - Steels. Micrographic determination of the apparent grain size* - was used to evaluate the steel grain size. The microstructure of the cast steel basic material (Fig. 8, left) consists of ferritic and perlitic grains 10 to 30 µm large with the grain size index G, the value of which is 8, specified in compliance with EN ISO 643. In the heat-affected zone, transformed thickened austenitic grains (Fig. 8 on the right) occurred. Their size varies between 40-50 µm with the grain size index 6. The grain size increases with a considerable variance ranging from about 40 up to 150 µm in a weld metal (Fig. 9 on the right). The grain size index G reaches the value 4 in this case. However, obtained values are not adverse in terms of the strength of the resulting casting, and microstructure is considered satisfactory.

5. Conclusion

Based on the results obtained in the experimental part, we can state that the proposed welding procedure can be considered correct, since all performed tests have been satisfactory. Critical limits for non-destructive tests, as well as those applicable for mechanical properties testing have not been exceeded, and the values met the requirements specified in relevant standards. Pore-type defects in a weld joint are typical for MAG technology, however their dimensions do not affect the integrity of a joint, nor they exceeded permitted limit values.

Based on the conditions specified in EN ISO 11970 and EN ISO 15614-1, the approved procedure can be applied to the weld joints.

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